LA-UR-12-21927

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Title: Moderate Velocity Ball Impact of a Mock High-Explosive

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Intended for: Society for Experimental Mechanics, 2012-06-11 (Costa Mesa, California, United States)

Moderate Velocity Ball Impact of a Mock High-Explosive

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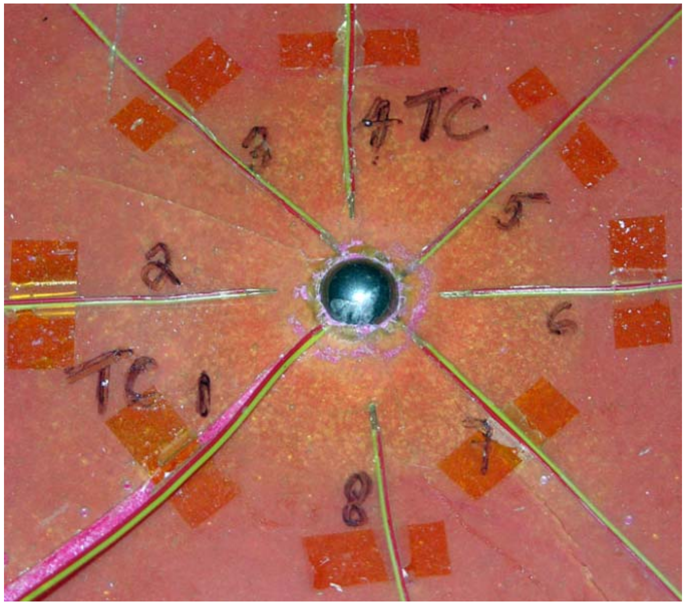

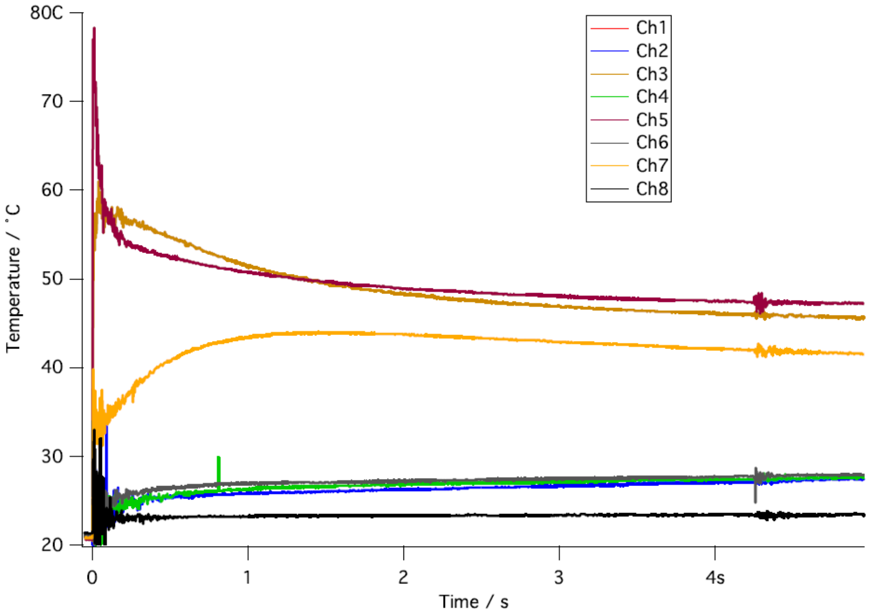

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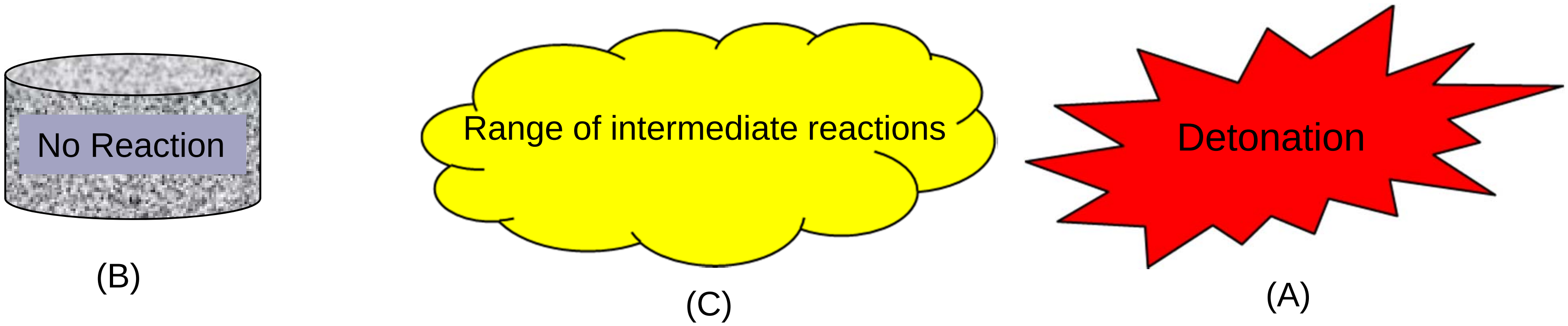
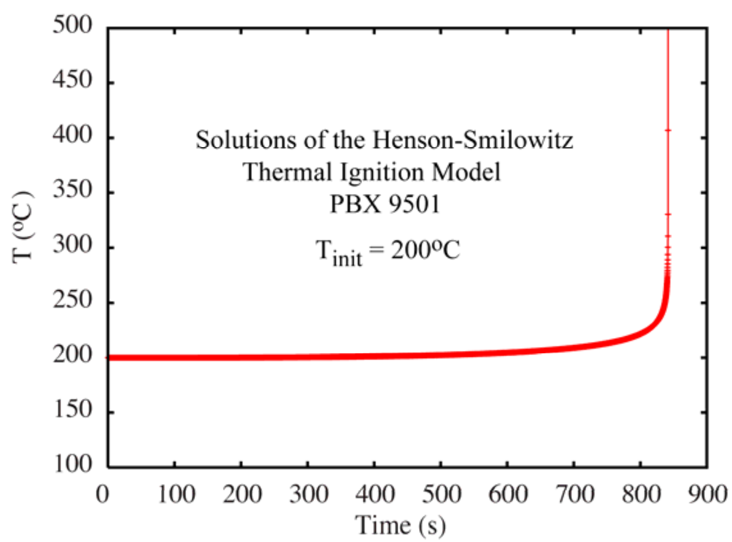
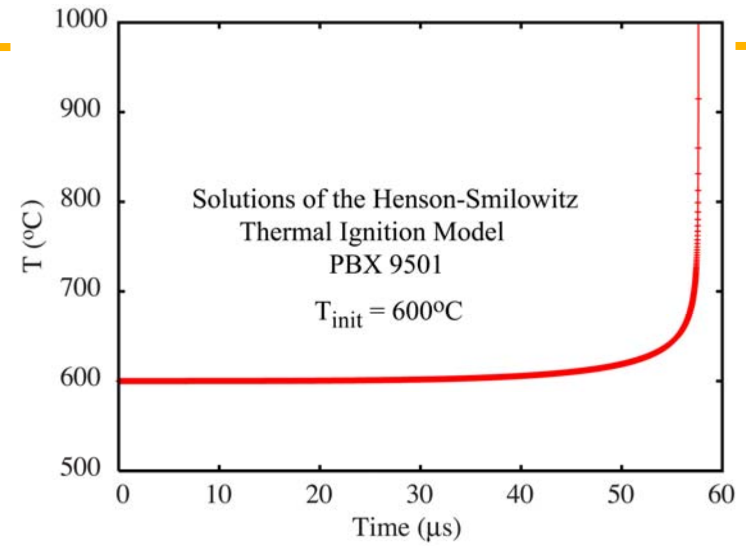
High explosives react from mechanical or thermal impulse



- Material properties can influence detonation in HE from mechanical insults through inelasticity
- (A), no reaction (B), a range of intermediate reactions, and (C) in between
- Time for “thermal run away” may be ***long***!

Solutions of Henson-Smilowitz Thermal Ignition Model





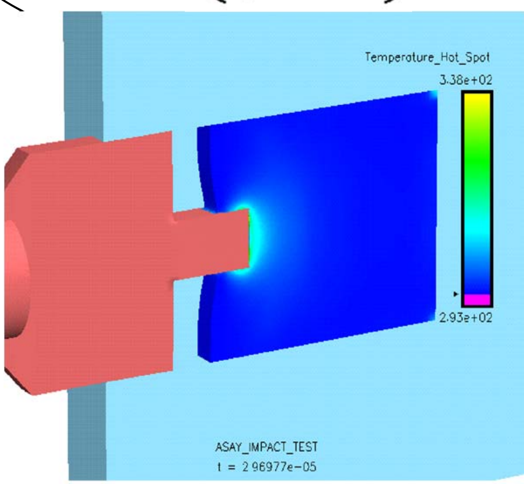
- Initial temperature ***strongly*** affects time to thermal run away
- Arrhenius reaction rate kinetics
- Important to accurately model temperatures in simulations

For non-shock ignition problems we need to *couple* a mechanical constitutive model with a thermal ignition model

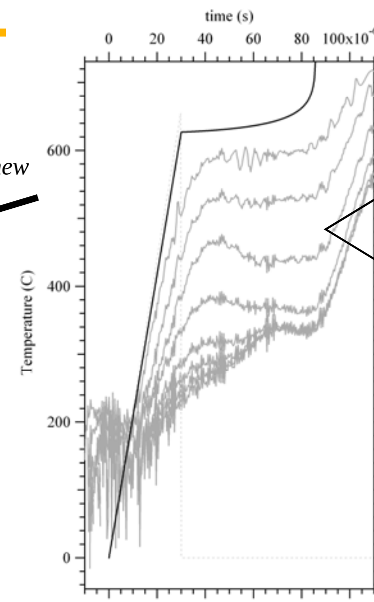
(1)

HE Constitutive Model

$$\left\{ s_{ij}, P, T \right\}$$



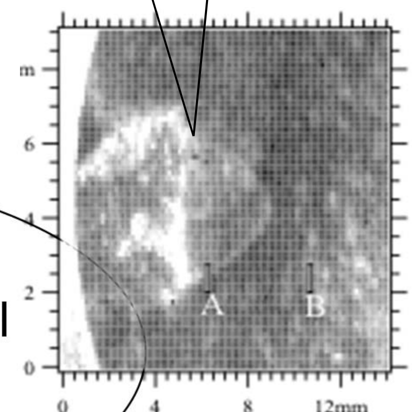
$T = \bar{T}, P_{new}$



A crucial point: T is the continuum-scale temperature

80µm

$\bar{T}$

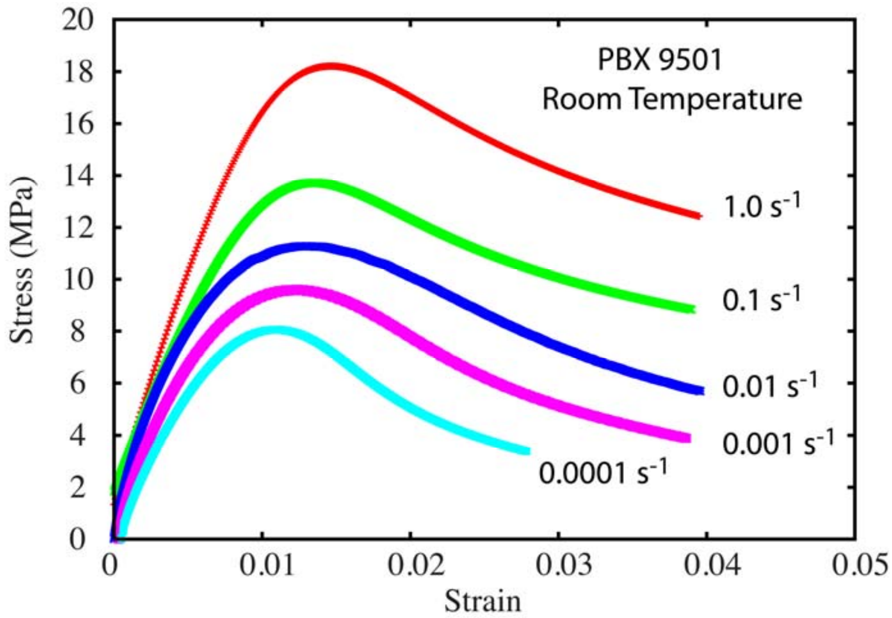


T

(2)

Henson/Smilowitz Thermal Initiation Model

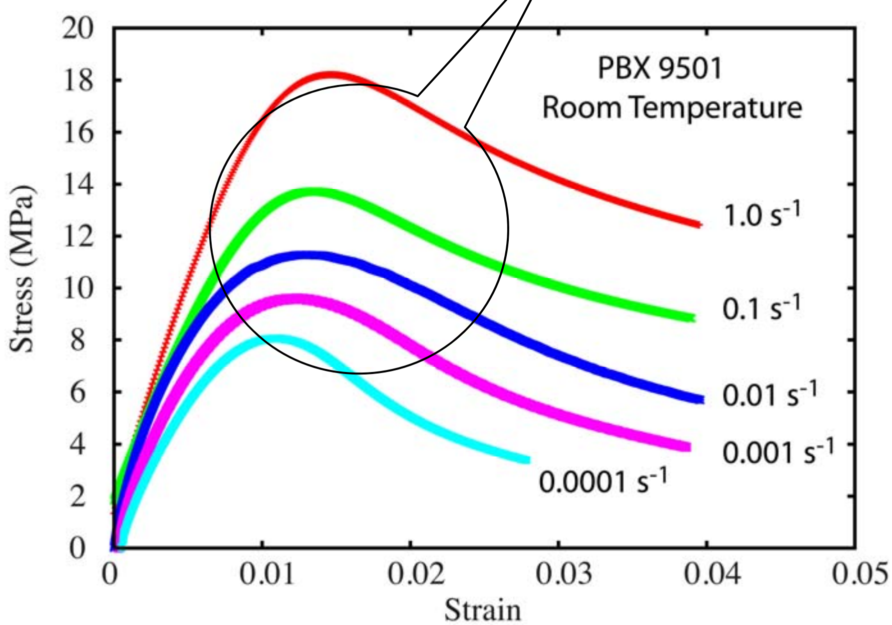
Constitutive Modeling: Stress-Strain Response of Many Plastic Bonded Explosives



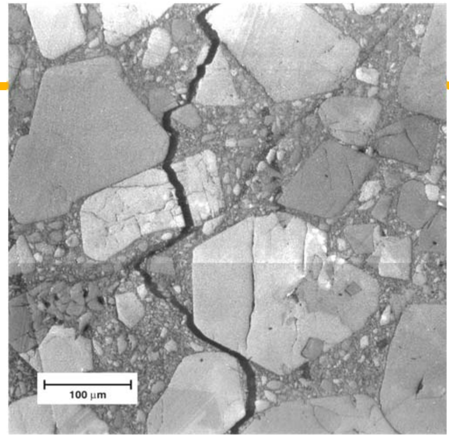
Experimental stress-strain data from D. Graff-Thompson et al. (LANL)

Stress-Strain Response of Many Plastic Bonded Explosives

Damage by micro- to macro-crack growth



Macrocrack: *In situ* observations in tension



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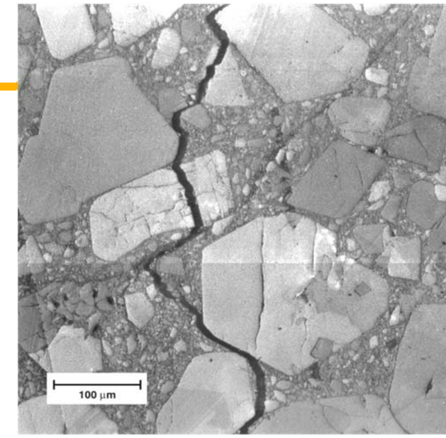

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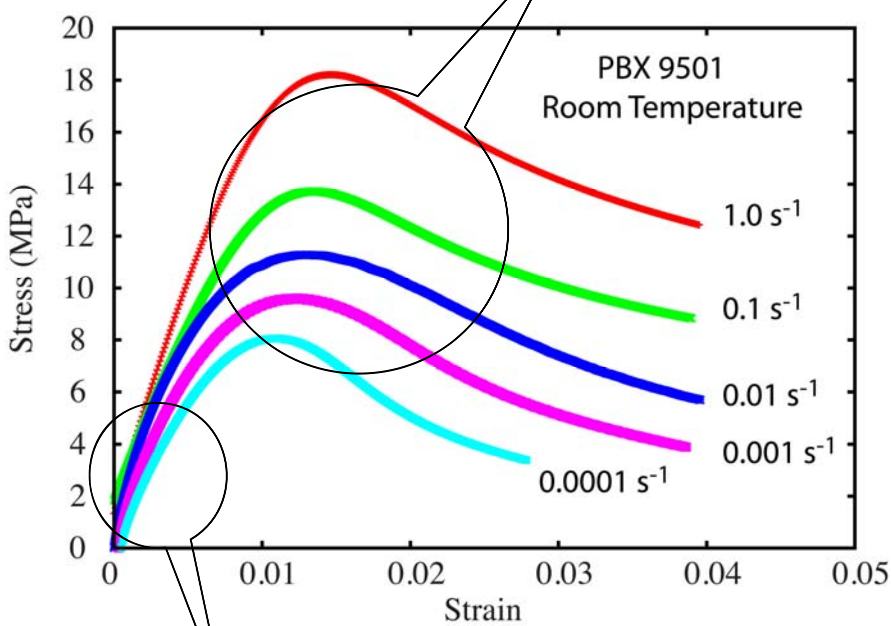
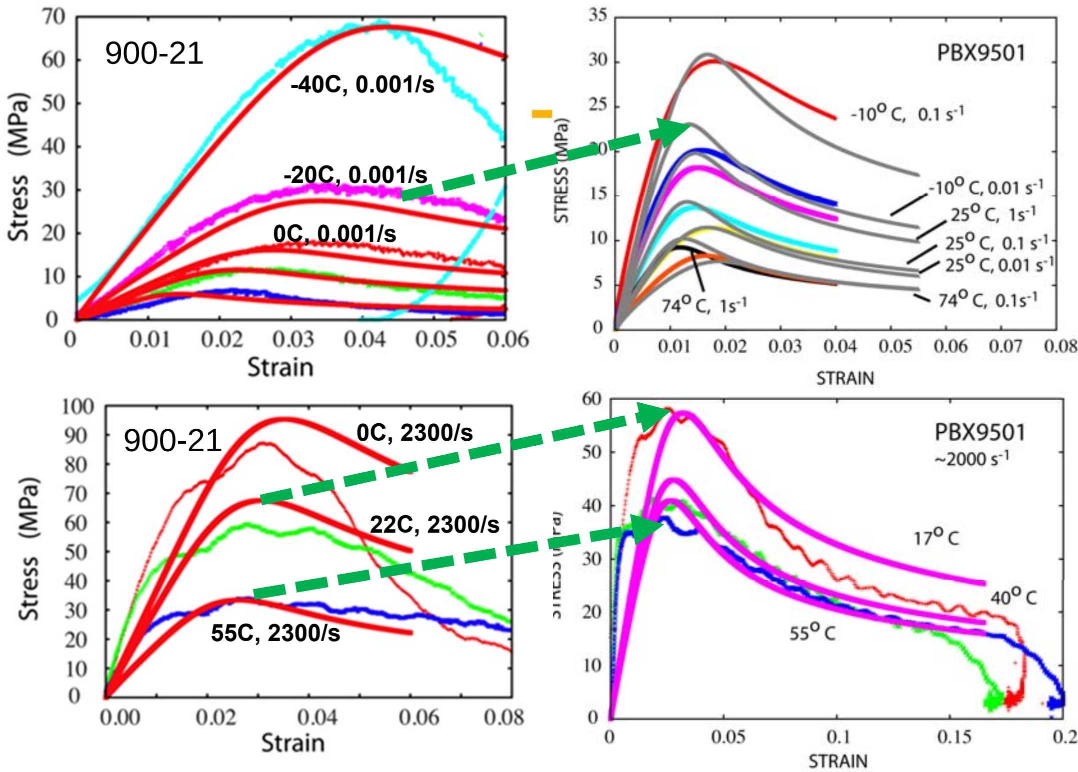


Experimental stress-strain data from D. Graff-Thompson et al. (LANL)

Viscoelastic temperature and rate rate dependence (derived from polymer binder)

ViscoSCRAM is a macro-scale model that captures the essence of the viscoelastcity and the micro-scale crack growth through continuum solid mechanics modeling

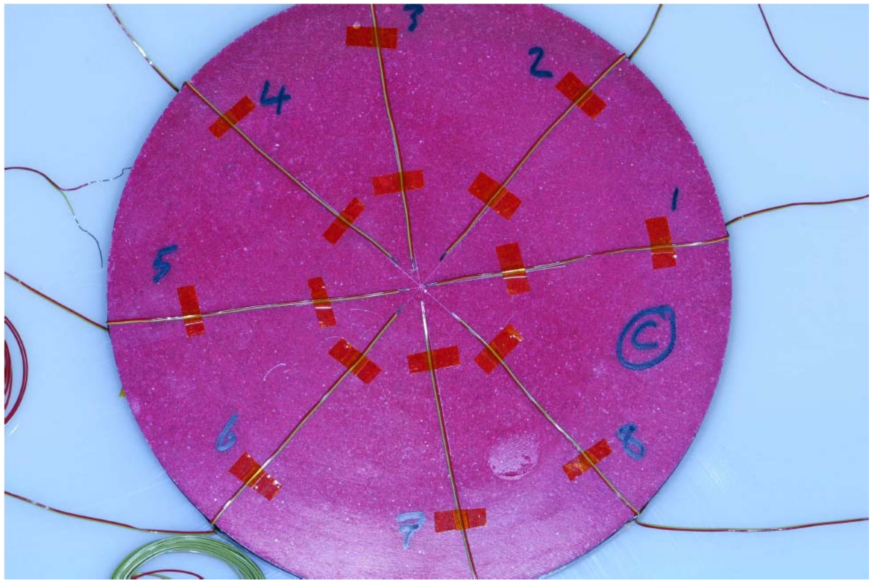
900-21 is an inert mechanical mock for PBX 9501



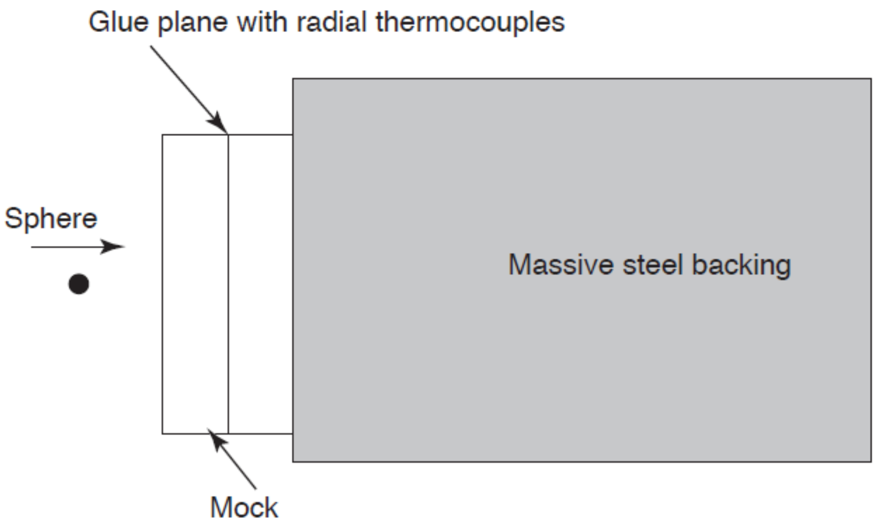
- Mechanical properties similar but not identical
- 900-21 consists of barium nitrate ($Ba(NiO_{3)2})$) with a plasticized estane binder
- A Mie-Grüneisen equation of state (EOS), with parameters adjusted to 9501

900-21 sandwich targets contained 8 thermocouples at the midplane

Sandwich midplane before bonding



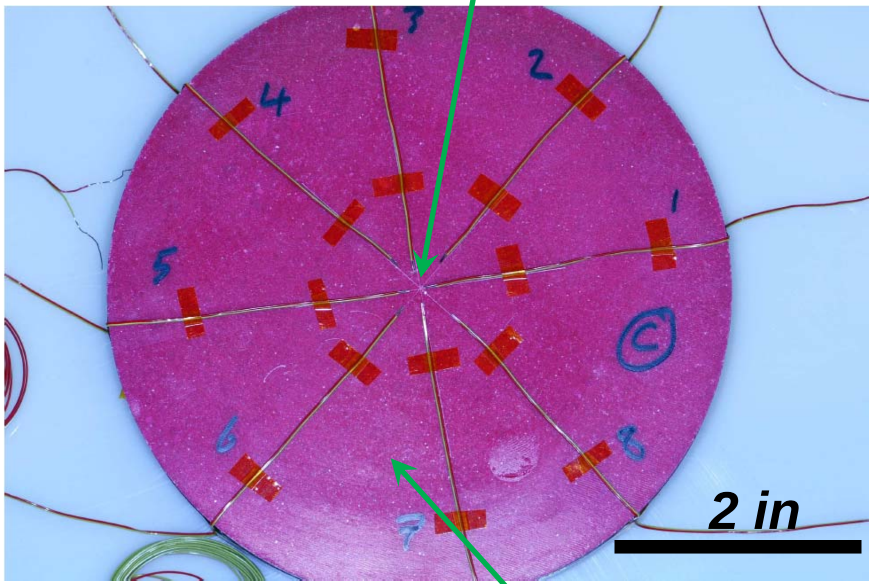
Target preloaded to anvil to allow compression but exclude tensile reflections



Two successful shots were conducted. The setup for each was slightly different.

Shot C

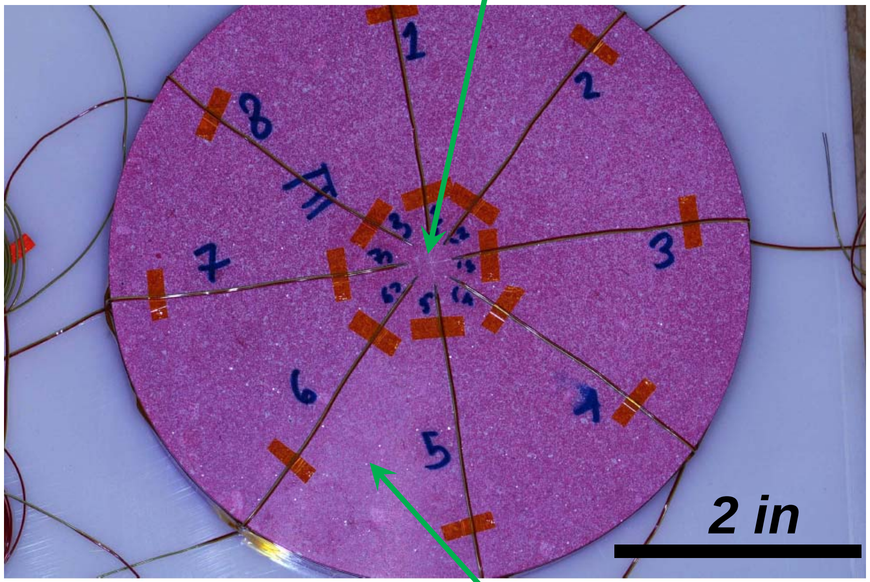
Thermocouple radial distance varied widely



Surface finish as-consolidated

Shot E

Thermocouple radial distance more tight



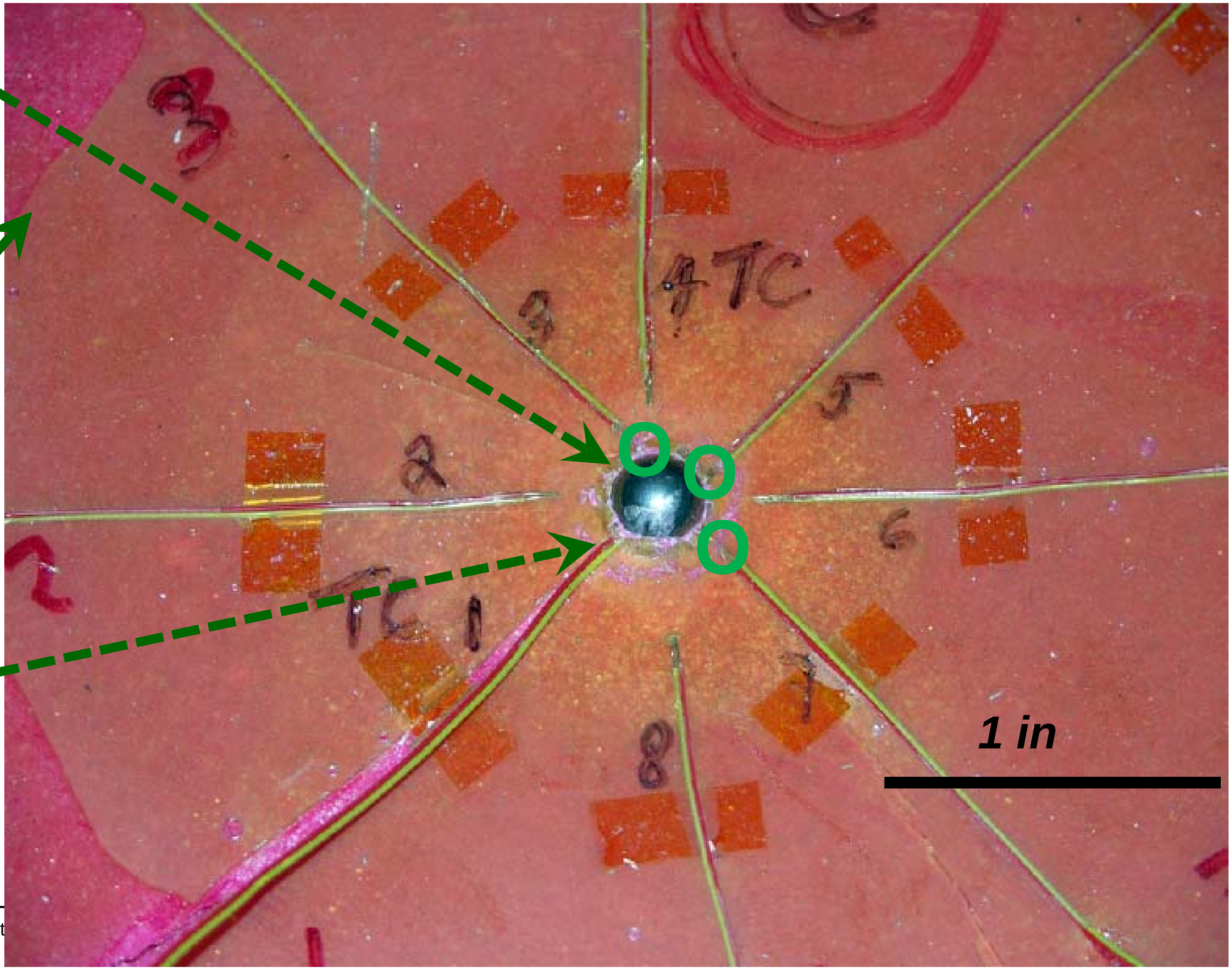
Machined (rough) surface finish

Projectile in Shot C (709 m/s) arrested at thermocouple plane showing temperature rise at *ball affected zone*

Ball equator right at thermocouple layer

Bond layer delaminated due to low adhesion

TC-1 destroyed by ball



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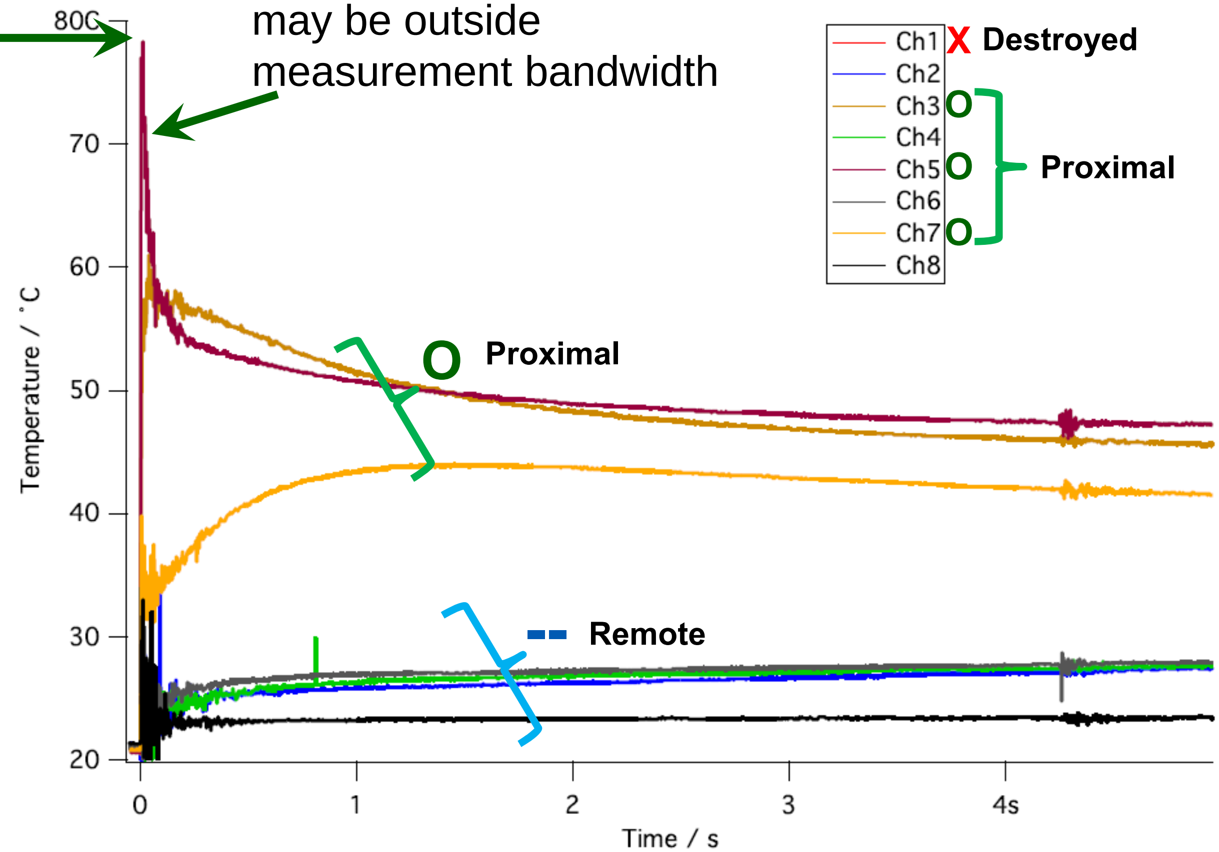
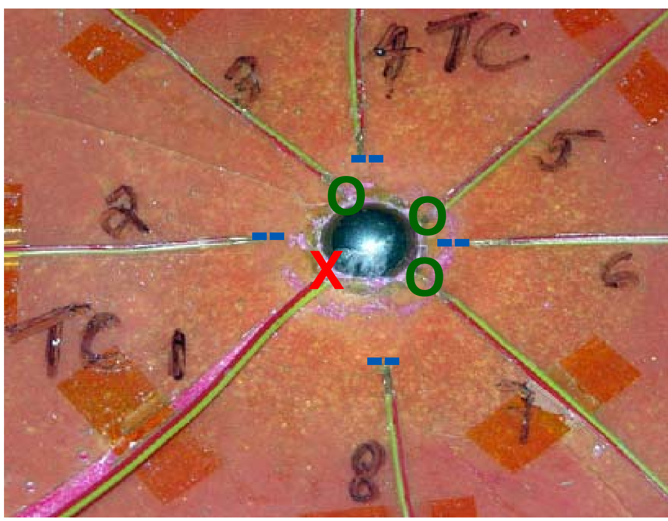
Three thermocouples were nearly in contact with ball during Shot C. Peak temperature rise was 56.7 K.

Maximum temperature rise: 57.6 K

Actual peak and rise time may be outside measurement bandwidth





NNSA

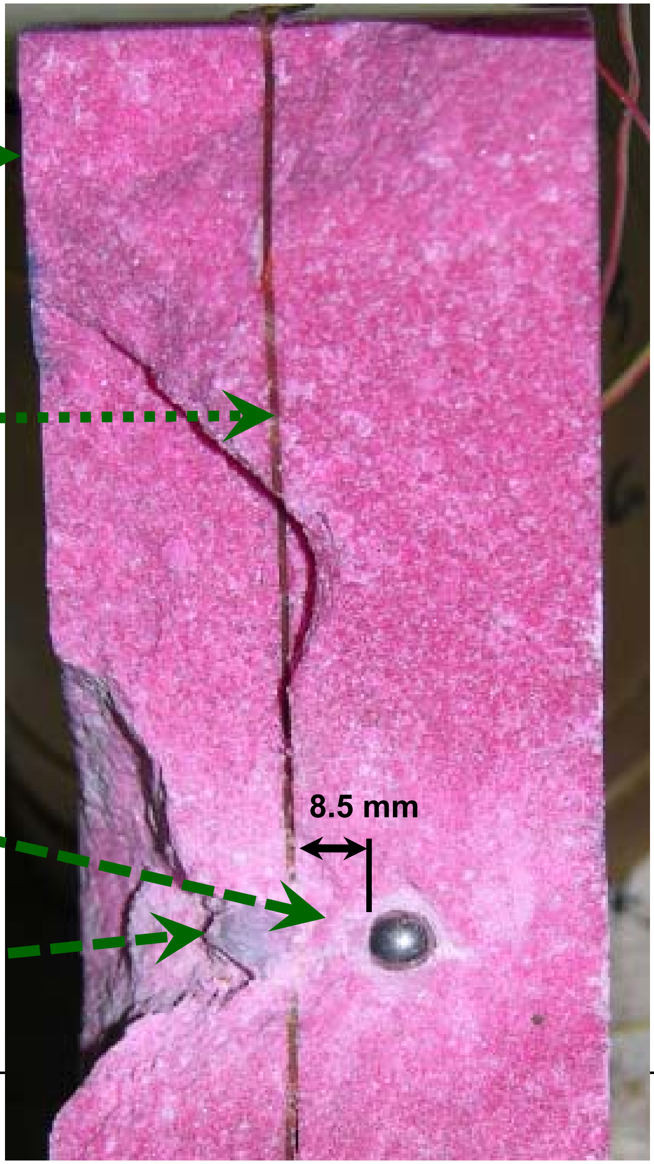
The projectile in Shot E (733 m/s) arrested 8.5 mm past the TC plane, giving temperature rise in the *inelastic wake*

Reduced thickness incident layer

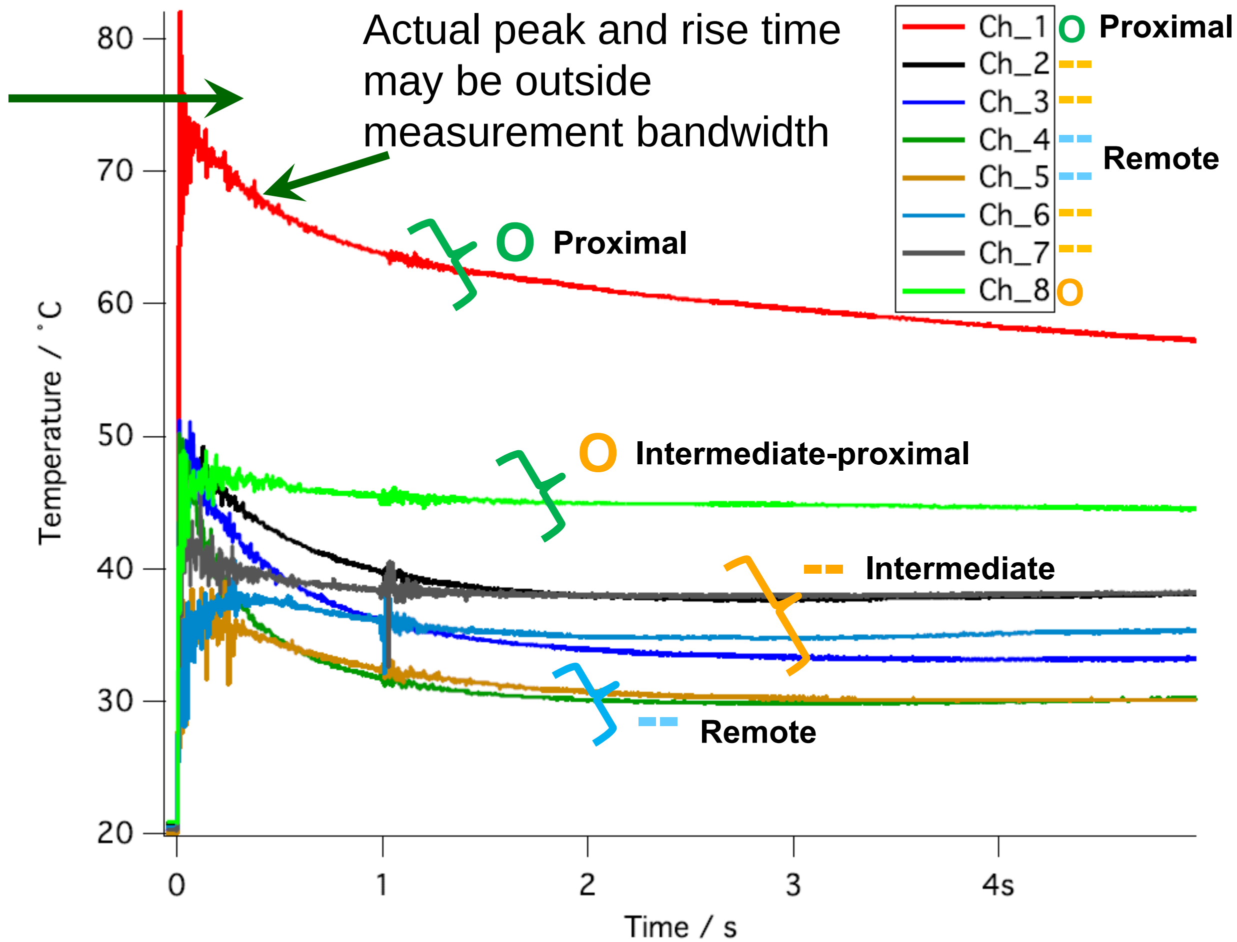
Bond layer adhesion much stronger with machined faces

Debris field completely encloses ball path

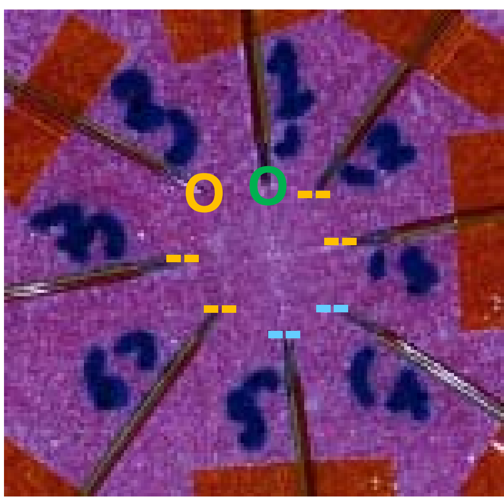
Obturator



TC channel 1 measured a peak temperature rise of 61.7 K. All other channels measured ΔT 10-30 K.

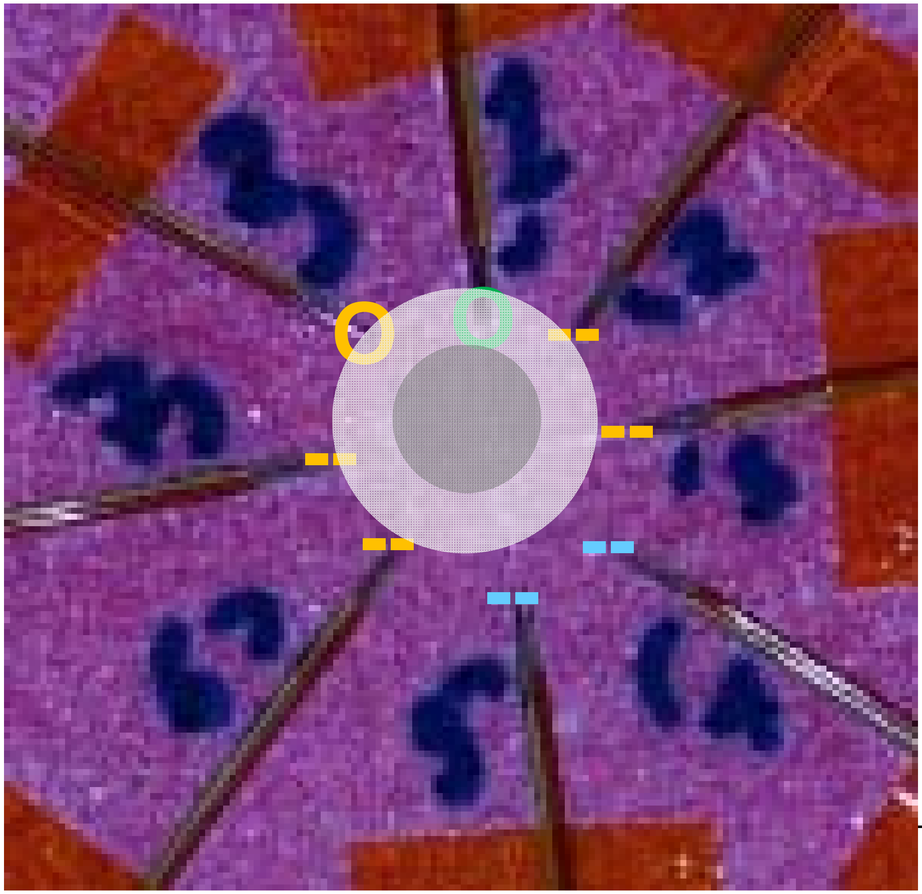


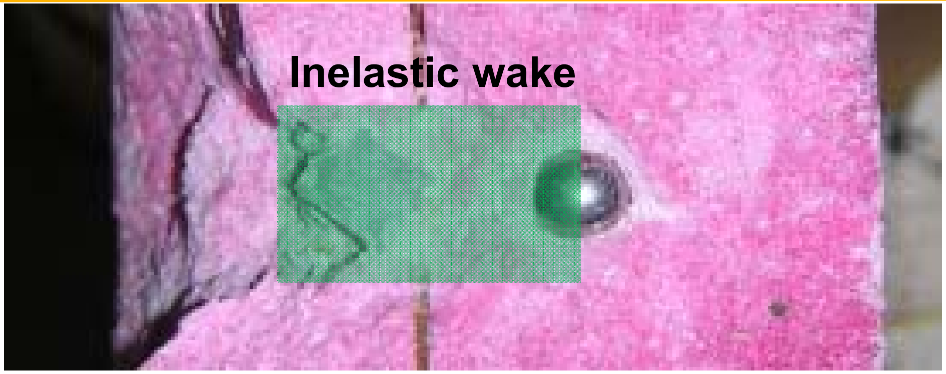
Improved bond made disassembly of TC plane impossible.

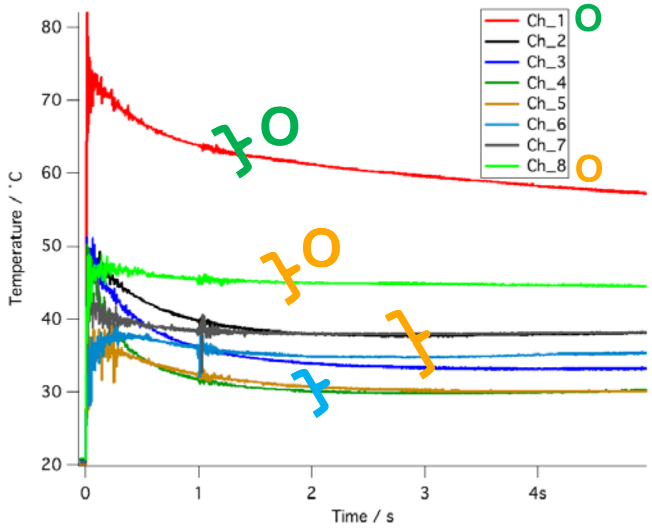


Approximated ball- and wake-affected regions indicate higher temperatures nearer to ball in damaged zone

Approximated ball and wake positions



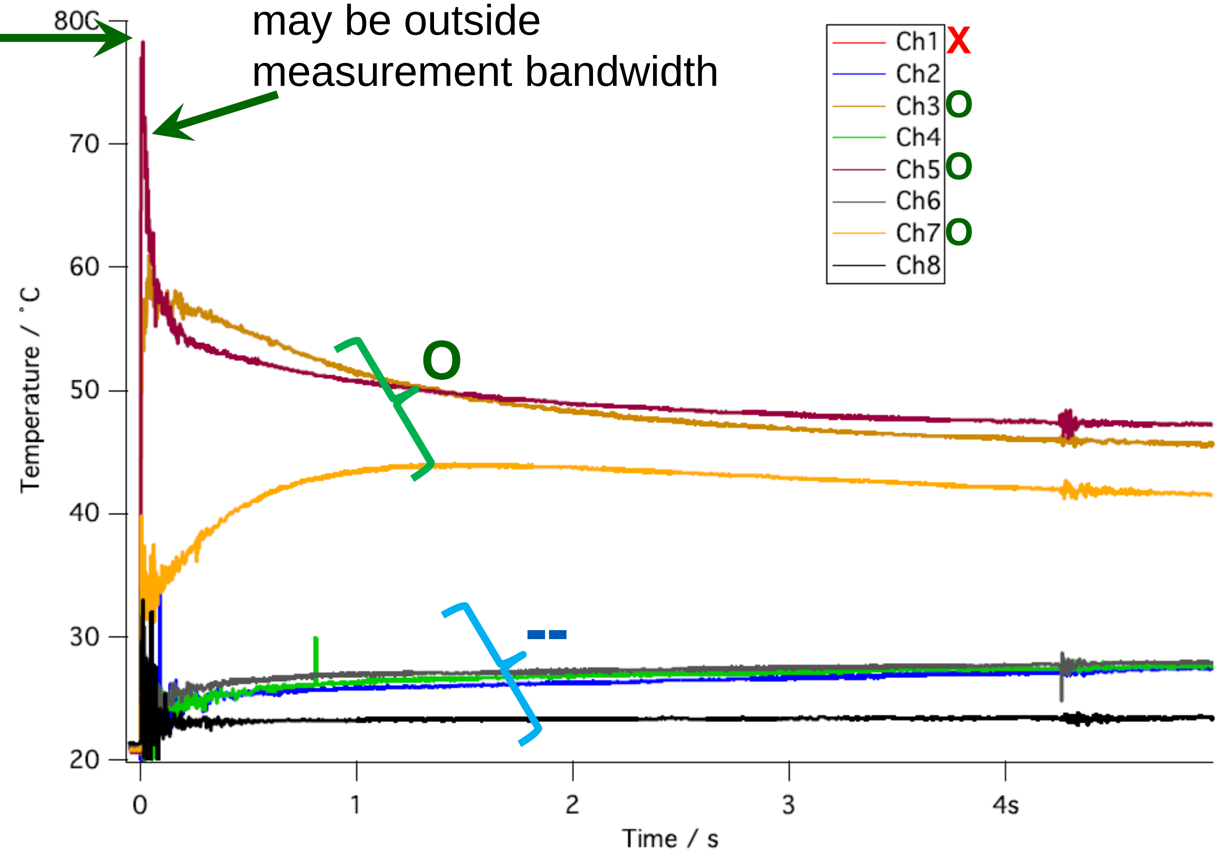




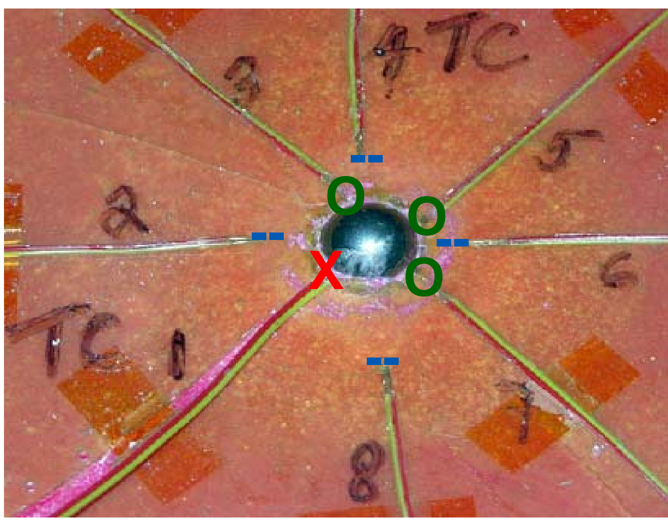
Limitation: The TC amplifier bandwidth was 500 Hz, possibly smearing and lowering temperature peak

Apparent temperature rise: 57.6 K

Actual peak and rise time may be outside measurement bandwidth



Thermal conductivity of TC is ~2 times PBX



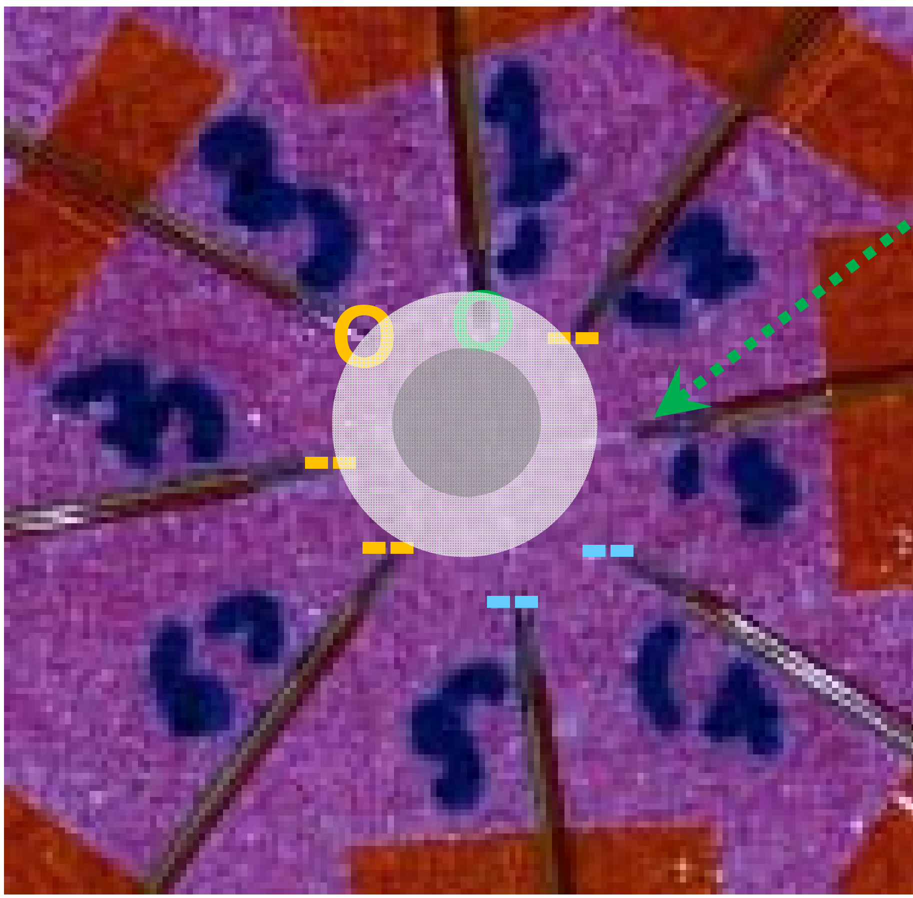
Heat capacity of TC is ~60 times PBX

Limitation: TCs measure averaged temperature field and affect apparent outcome

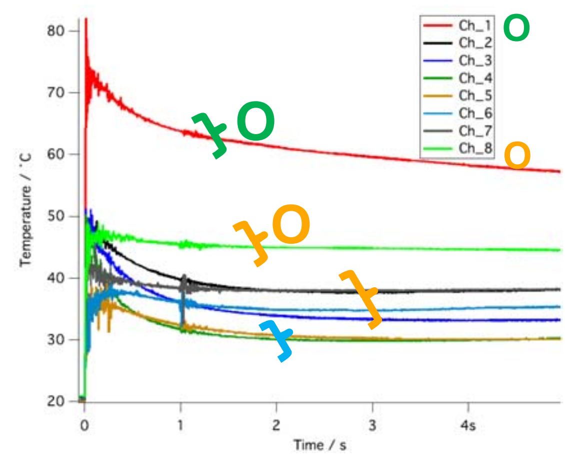
Thermal conductivity of TC is ~2 times PBX

Heat capacity of TC is ~60 times PBX

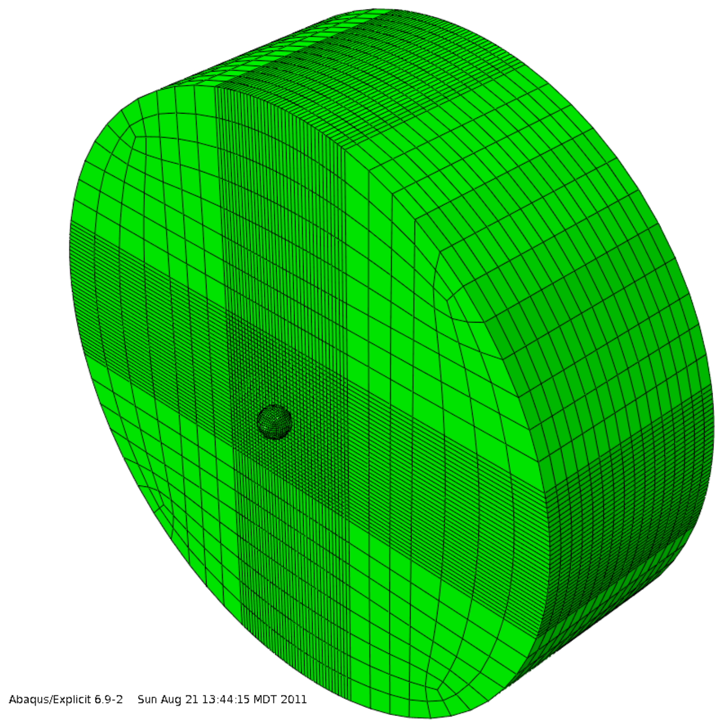
Improves quality of temperature measurement

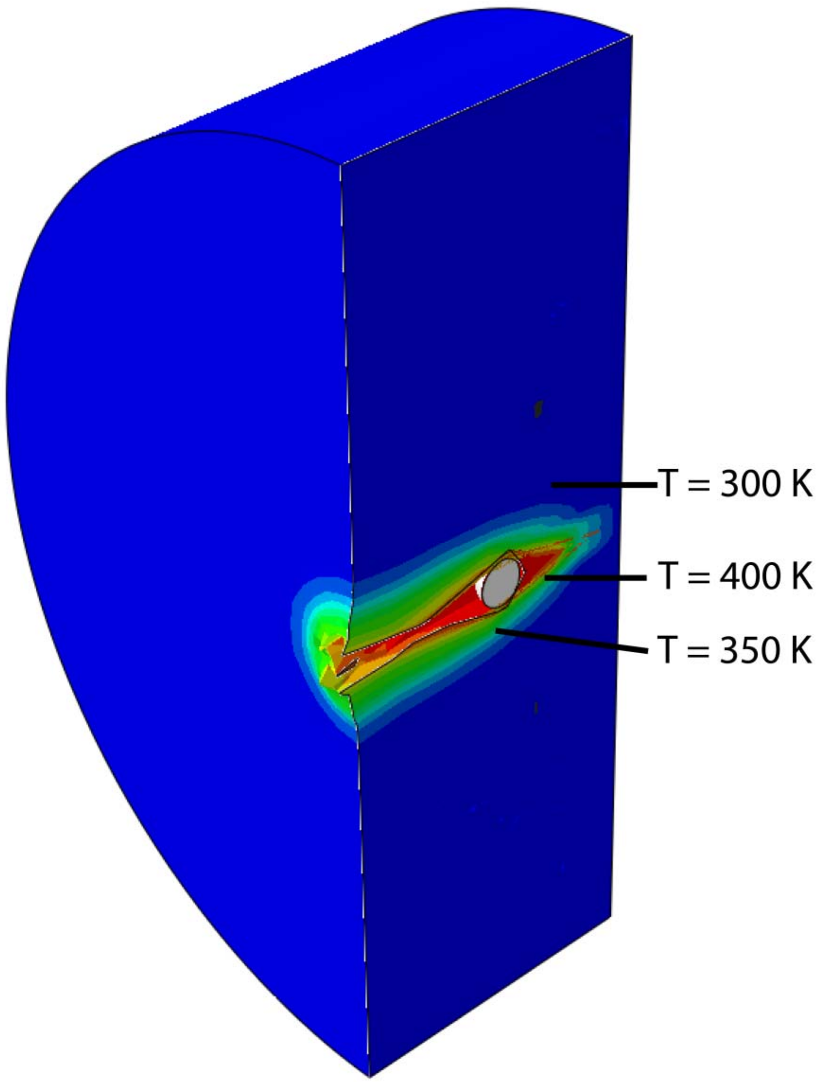


Thermocouple wires 0.25 mm diameter; approx. averaging size scale



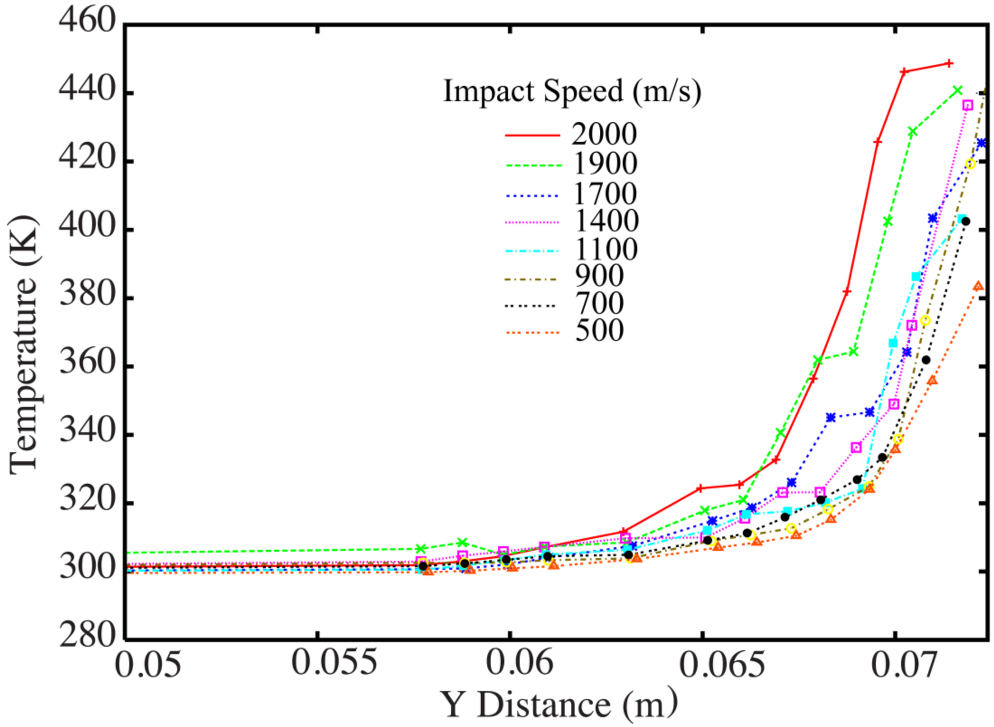
Simulation in ABAQUS/Explicit with ViscoSCRAM VUMAT

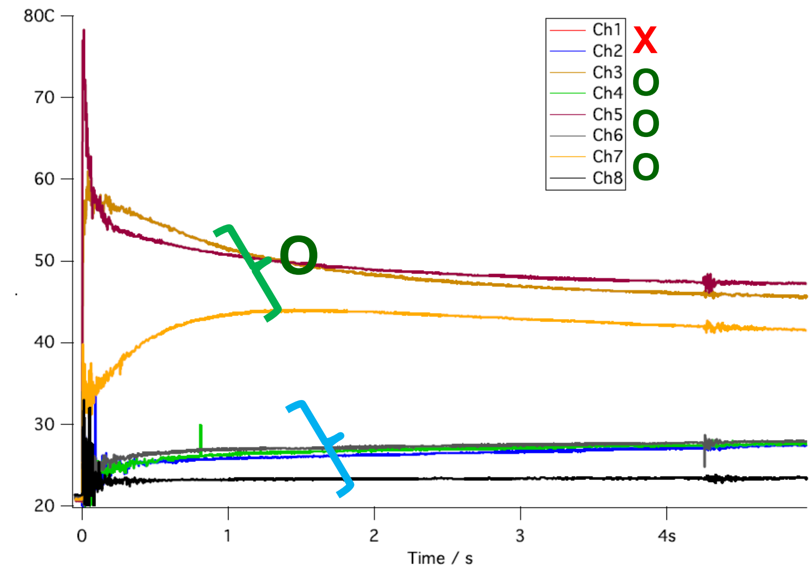




FEA predicted temperature rise comparable to experiment

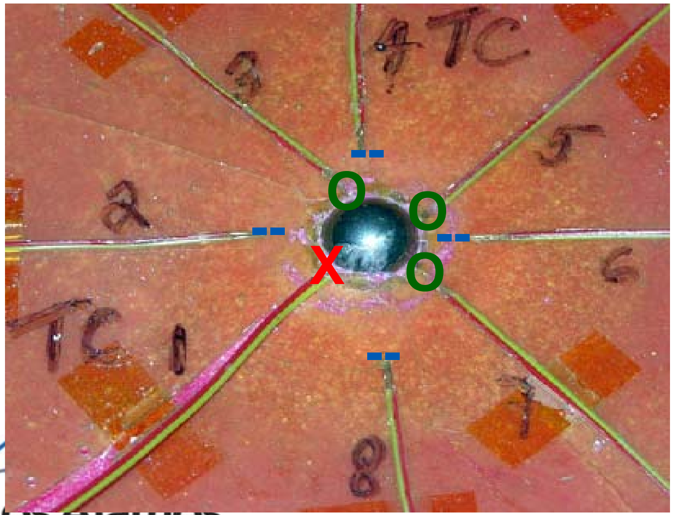
- **Both ~80-100 K for 700 m/s within 1 mm of ball**
- **Higher velocities predict moderate increase in temperature**
- **Motivates work with flat projectiles**
  - ***(increased shear and damage)***

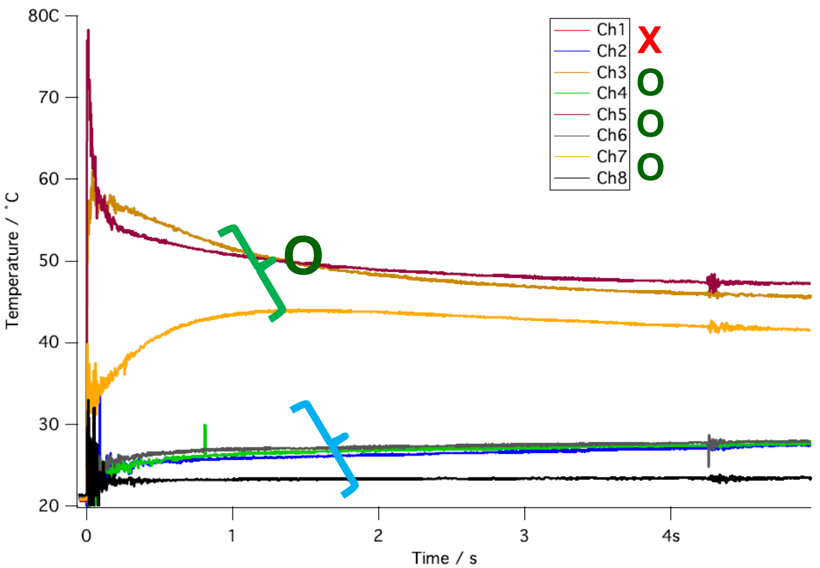




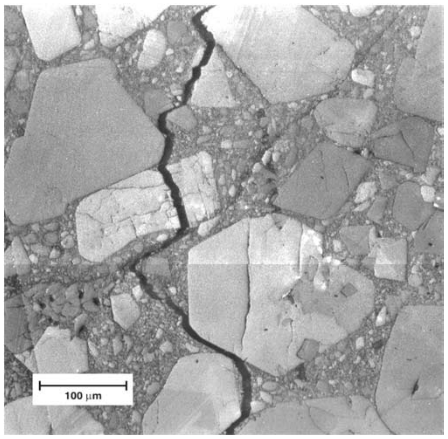
Conclusion: TC averaged peak temperature during ~700 m/s ball impact is likely below 100 C

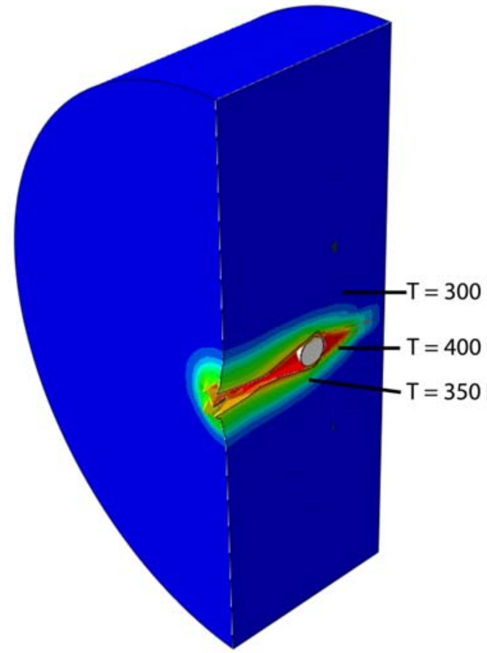
- Intrinsic time scale of TC measurement: ~100 Hz
- Improved time resolution must be optical
- Impact experiments are planned with round and flat penetrators with high resolution thermal cameras

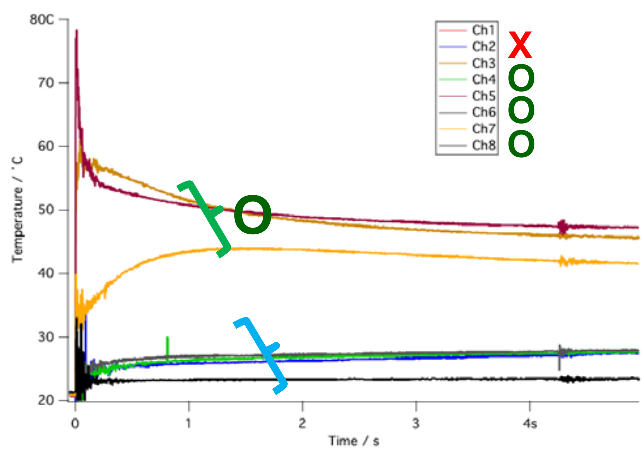




Thank You


100 µm


T = 300 K
T = 400 K
T = 350 K


80C
70
60
50
40
30
20
Temperature / °C
0
1
2
3
4s
Time / s
Ch1
Ch2
Ch3
Ch4
Ch5
Ch6
Ch7
Ch8
X
O
O
O
O

Abstract

Modeling of thermal and mechanical events in high-explosive materials is complicated by the composite nature of the material, which experiences viscoelastic and plastic deformations and sustains damage in the form of microcracks that can dominate its overall behavior. A mechanical event of interest is projectile interaction with the material, which leads to extreme local deformation and adiabatic heating, which can potentially lead to adverse outcomes in an energetic material. Simulations of such an event predicted large local temperature rises near the path of a spherical projectile, but these were experimentally unconfirmed and hence potentially non-physical. This work concerns the experimental verification of local temperatures both at the surface and in the wake of a spherical projectile penetrating a mock (unreactive) high-explosive at ~700 m/s. Fast response thermocouples were embedded radially in a mid-plane of a cylindrical target, which was bonded around the thermocouples with epoxy and recorded by an oscilloscope through a low-pass filter with a bandwidth of 500 Hz. A peak temperature rise of 70 K was measured both at the equator of the projectile and in its wake, in good agreement with the temperature predicted in the minimally distorted elements at those locations by a finite element model in ABAQUS employing the ViscoSCRAM constitutive model. Further work is needed to elucidate the extreme temperature rises in material undergoing crushing or fragmentation, which is difficult to predict with meshed finite element methods due to element distortion, and also challenging to quantify experimentally.